

1986

## A Physiological Comparison of Two Rowing Ergometry Protocols on Performance in Male Oarsmen

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**A PHYSIOLOGICAL COMPARISON OF TWO ROWING  
ERGOMETRY PROTOCOLS ON PERFORMANCE**

**IN MALE OARSMEN**

**BY**

**GREGORY M. ADAMS**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF**

**MASTER OF SCIENCE**

**IN**

**PHYSICAL EDUCATION**

**UNIVERSITY OF RHODE ISLAND**

**1986**

MASTER OF SCIENCE THESIS  
OF  
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1986

## ABSTRACT

The purpose of this study was to examine the effect of two strategically different protocols performed on the Concept II rowing ergometer, on the physiological response and distance/time relationship in men's lightweight race rowing. Ten members of the University of Rhode Island men's lightweight crew team, eight of whom comprised the boat which won the 1984 Dad Vails Small College Championship, and two alternates volunteered for this study. Subjects performed a 3.5 mile "all-out" (AO) rowing protocol designed to simulate the length, duration, and strategy of traditional 2000 meter rowing race. Forty-eight hours later the subjects performed a second 3.5 mile protocol (P), designed to simulate the pacing strategy recommended for most endurance type races. Rowing performance was measured in elapsed time (min:sec) to complete the 3.5 mile protocols. Stroke rate (SR) was evaluated every thirty seconds (s) with the use of a stroke watch, while metabolic efficiency was determined by thirty second calculations of heart rate (HR), absolute oxygen consumption ( $\dot{V}O_2$ ), relative oxygen consumption ( $M\dot{V}O_2$ ), ventilatory equivalent ( $\dot{V}_E$ ), and respiratory quotient (RQ). Paired T-tests were applied to the forementioned to determine possible significant differences between the two testing protocols.

Total time taken to complete the two testing protocols was not significantly different, and almost identical between the tests. The mean time taken for completion being 379.6  $\pm$  8.13, and 380.3  $\pm$  8.31 seconds in the AO and P protocols, respectively. SR for the AO protocol was significantly higher during the first 30s and significantly lower from the

90s point to completion of the test. HR in the AO test was higher throughout the entire test, reaching significance at the 30s, 150s, and 270s marks.  $\dot{V}O_2$  was also higher throughout the entire AO test, reaching significance through the first 120s, and again at the 240s and 360s marks.

The average across all 30s group mean values for SR, HR, absolute and relative  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and minute volume were significantly higher throughout the AO protocol.

A significant difference was seen between the total energy costs of the two testing protocols, with the AO test cost being significantly higher. These difference, accompanied by almost identical times taken to complete the two tests, suggest that employment of the pacing strategy seen within the P protocol may result in more efficient mechanisms and effective utilization of energy sources in the working muscles, and may result in a greater use of "energy stores" over the last several hundred meters of 2000 meter race rowing.

## **ACKNOWLEDGEMENTS**

**The author would like to thank the following:**

**Committee members Dr. Leo O' Donnell and Mr. Jack Thompson for their support and input to this project.**

**Dr. Robert Sonstroem for his statistical guidance.**

**Susan Lindholm for her insight into the sport of race rowing as well as her expert assistance with the laboratory testing.**

**Frank Miller for his assistance in preparing for my laboratory testing as well as with guidance in formulating my study design.**

**My parents for their continued support and motivation throughout this project.**

**Lastly, a special thank you to Dr. Thomas G. Manfredi, Chairman of my Thesis Committee, for his support and guidance throughout this project. His dedication and committment to the exercise science field, and to the developement of the Human Performance Laboratory at the University of Rhode Island is unparralleled. This committment has made my association with the Human Performance Laboratory an invaluable one. To the continued growth and committment towards his program this thesis is dedicated.**

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## CHAPTER I

### INTRODUCTION

Race rowing has been determined to be one of the most demanding competitive endurance sports (Hagerman, Hagerman, and Mickleson, 1979; Jackson and Secher, 1976). Exercise testing on rowers has shown that a high aerobic capacity is an important ingredient for international rowing success (Hagerman et al., 1978; 1979; Mahler et al., 1984; Secher et al., 1982) with maximal aerobic capacities of oarsmen being among the highest recorded of any endurance athlete (DiPrampero et al., 1971; Jackson and Secher, 1976; Mahler et al., 1984; Nowacki et al., 1969).

Given the demands of a rowing regatta, which is 2000 meters in length for men, and lasts between six and seven minutes, a physiologically sound and efficient race strategy should presumably be employed. This has not been the case in rowing. Traditionally, oarsmen have violated recommended methods of pacing for endurance events which typically include a steady aerobic workload over the majority of the race with an anaerobically based sprint over the final 45 to 60 seconds of the race (Hagerman et al., 1979; Mahler et al., 1984). Rowers, however, begin races at extremely high energy expenditures and marked anaerobic response for the first 30 to 45 seconds followed by the "body" of the race, which is at a slower steady state performance level for the middle 4 to 5 minutes of the race. This is followed by another anaerobic sprint over the last 45 to 60 seconds (Hagerman et al., 1972; Hagerman et al., 1979). Race rowing split times show the first 250 meters to be the fastest, with the following 250 meter segments covered in a slower split time and the last 250 meters

being slightly faster (Hagerman et al., 1979). This strategy puts a great stress on the oxygen transport systems and increases anaerobiosis (Hagerman et al., 1972), which produces maximal lactate levels at the start of the race. This increase in anaerobiosis occurs when the individual reaches his or her anaerobic threshold which is defined as being the point at which there is a non-linear increase in ventilatory equivalent/oxygen consumption ( $VE/\dot{V}O_2$ ), while ventilatory equivalent/carbon dioxide ( $VE/\dot{V}CO_2$ ) remains unchanged (Wasserman et al., 1973). These maximal lactate levels must be endured for the duration of the race (Hagerman et al., 1979).

Maximal stress testing to study oarsmen's physiologic capabilities has been done primarily on treadmill tests or on bicycle ergometers (Clark et al., 1963; Secher et al., 1982) until the rowing ergometer was developed. Studies have found that the results obtained on the rowing ergometer closely simulate those during actual rowing (Hagerman et al., 1979; Mahler et al., 1984). Due to its specificity, however, the rowing ergometer has become the preferred method of exercise testing for oarsmen (Cunningham et al., 1975; Hagerman et al., 1978, Hagerman et al., 1979; Mickleson and Hagerman, 1982).

Physiological parameters have primarily been evaluated on two different protocols on rowing ergometers; a six-minute "all-out" (6M-AO) test, and a progressive, incremental (P) exercise test to exhaustion (Mahler et al. 1984). The 6M-AO test is used for its close approximation of intensity, duration, and racing strategy to competitive rowing (Hagerman et al., 1978, Hagerman et al., 1979; Mahler et al., 1984). From a "standing start", each oarsmen rows the first ten strokes with maximal effort at a cadence of 40 strokes  $\cdot$  minute<sup>-1</sup>. The stroke cadence is then reduced to

34-36 strokes · minute<sup>-1</sup> until the last thirty seconds of the test when the stroke rate is increased to 40-42 strokes · minute<sup>-1</sup> for the final sprint (Mahler et al., 1984).

The P protocol corresponds to the traditional form of exercise testing seen during treadmill and bicycle ergometry tests (Micklethorn and Hagerman, 1982). Recently, Mahler et al., (1984), have compared and found no significant difference in peak  $\dot{V}O_2$  or other peak physiologic parameters, with each test lasting between six and seven minutes before exhaustion of the subject. Although each protocol has its advantages, there has been no comparison of distance traveled through the different stages of an "all-out" test versus a "pacing" (P) test following the recommended pacing strategy of most endurance races. Since success in any race is determined by the comparison of time needed to cover a set distance, a study of this distance/time relationship seems in order. Understanding of this distance/time relationship between the P test, which would seem more physiologically efficient, and the 6M-AO test, which simulates the traditional approach to racing, would seem to be imperative in developing a deeper understanding of the physiological parameters that elicit optimal rowing performance.

### STATEMENT OF THE PROBLEM

The purpose of this study was to examine the effect of two strategically different protocols performed on the Concept II rowing ergometer, on the physiological response, and time/distance relationship in men's lightweight race rowing. Ten members of the University of Rhode

Island men's lightweight crew team volunteered for this study. Eight of the subjects comprised the boat which won the 1984 Dad Vails Small College Championship. The remaining two were alternates to that boat.

The ten subjects performed a 3.5 mile "all-out" rowing protocol, designed to simulate the length, duration, and strategy of traditional 2000 meter race rowing. Forty-eight hours later the subjects performed a second 3.5 mile protocol, designed to simulate the pacing (P) strategy of most endurance type races.

Split times were taken at each .5 mile. Also, heart rate (HR), absolute oxygen consumption ( $\dot{V}O_2$ ), relative oxygen consumption ( $M\dot{V}O_2$ ), ventilatory equivalent ( $V_e$ ), fraction of expired oxygen ( $F_{EO_2}$ ), fraction of expired carbon dioxide ( $F_{ECO_2}$ ), carbon dioxide production ( $\dot{V}CO_2$ ), and respiratory quotient (RQ) were calculated every thirty seconds for each subject. In addition, body compositions were also obtained for each subject.

Each oarsman was evaluated on each protocol in a laboratory setting. Rowing performance was measured in elapsed time (min:sec) to complete the 3.5 mile protocols. Comparisons of each thirty second recordings of HR,  $\dot{V}O_2$ ,  $V_e$ ,  $F_{EO_2}$ ,  $F_{ECO_2}$ ,  $\dot{V}CO_2$ , and RQ, were used to determine metabolic efficiency.

The following hypothesis were tested;

#### HYPOTHESIS I

Subjects will achieve a faster time while rowing 3.5 miles using the pacing protocol as opposed to the traditional "all-out" protocol.

## **HYPOTHESIS II**

Mean heart rates will be higher in subjects performing the traditional "all-out" protocol when compared to the pacing protocol.

## **HYPOTHESIS III**

The mean energy cost of the P protocol will be less than the "all-out" protocol as measured by mean absolute and relative oxygen consumption.

## **DEFINITION OF TERMS**

For the purpose of this study , the following definitions were used:

**Beathing Frequency** - (BF) - The number of exhalations recorded per minute.

**Fraction of Expired Carbon Dioxide** - ( $FeCO_2$ ) - The percentage of expired air which is composed of carbon dioxide.

**Fraction of Expired Oxygen** - ( $FeO_2$ ) - The percentage of expired air which is composed of oxygen.

**Heart Rate** - (HR) - The number of times the heart beats in one minute.

**Maximal Oxygen Uptake** - ( $VO_2 \text{ max}$ ) - The maximal amount of oxygen an individual can consume during physical work while breathing at sea level.  $VO_2 \text{ max}$  can be expressed in absolute ( $\text{liters} \cdot \text{min}^{-1}$ ) and relative ( $\text{ml} \cdot \text{kg} \cdot$

min<sup>-1</sup>) terms.

**Minute Ventilation** - ( $V_e$ ) - The volume of air expired in liters · minute<sup>-1</sup>.

**Power Ten Strokes** - The point or points in a rowing regatta in which the stroke rate increases and all out effort is given on ten consecutive strokes.

**Respiratory Quotient** - (RQ) - The relationship of the quantity of carbon dioxide produced to that of oxygen consumed. ( $RQ = V_{CO_2} / V_{O_2}$ ).

**Stroke Rate** - (SR) - The number of strokes performed per minute.

**Ventilatory Equivalent** - ( $V_e / V_{O_2}$ ) - The ratio of minute volume to oxygen consumption.

### **DELIMITATIONS**

This study was delimited to :

1. A group of ten competitive male oarsmen ranging from 18 to 25 years of age.
2. Physical and physiological measurements which were performed in the Human Performance Laboratory at the University of Rhode Island.
3. Subjects completing the same physical workouts on each testing day and on the days between testing.



## **LIMITATIONS OF THE STUDY**

**The study was limited in the following respects :**

- 1. The study was limited to ten male volunteers of the University of Rhode Island's men's lightweight crew team.**
- 2. Subjects were near peak condition rather than at peak condition at the time of testing.**
- 3. The order of administration of the A0 and P protocols was not randomized.**

## **BASIC ASSUMPTIONS**

**It was assumed that all the oarsmen performed to maximal effort on each of the 3.5 mile testing protocols.**

## CHAPTER II

### REVIEW OF LITERATURE

#### Early Research

As early as 1920, Liljestrand and Lindhard described their attempts to measure oxygen consumption, heart rate and cardiac output during rowing. Henderson and Haggard followed in 1925 with a study of estimated energy expenditure and power output of the 1924 Olympic eight oared crew gold medalists. Open spirometry was used to indirectly measure oxygen consumption during and after ergometric work. Power output was determined by calculations using speed and weights while rowing a towed boat and by using a rowing ergometer of sophisticated design which used an oar as a pump to move water against a resistance. The energy output of a typical oarsmen was reported to exceed by 30% to 60 % the energy yield available through aerobic means. During the most strenuous workloads, an oarsmen produced oxygen deficits of between 4 and 8 liters. The authors' subjective judgement was that subjects in this study had not been exercised to maximal limits of their aerobic energy capacity (Henderson and Haggard, 1925). These studies, though primitive when compared to today's methods and technology, opened the door to rowing research. Of equal importance, the innovation of these scientist as applied to testing apparatus, identified the importance of specificity of testing during actual performance, a procedure currently in use when measurements of optimal performance are

desired.

## Physical Characteristics of Rowers

International caliber oarsmen and oarswomen tend to be tall, muscular, and lean, with an age range that shows wide variability, ranging from 18 to 36 years (de Gary et al.; 1974). Oarswomen are rather tall athletes with heavy skeletomuscular structure (Hebblienick et al., 1980). Measurements collected on more than 600 oarsmen (Hagerman et al., 1979) have shown the average height of heavyweight oarsmen to be 192 centimeters with an average body weight of 88 kilograms. Percentage of fat in heavyweight oarsmen has shown a decline in recent years with reports of averages between 9% and 10 %.( Hagerman, 1984). An earlier study (Hagerman et al., 1979) reported an average of 11 % body fat for elite heavyweight oarsmen. Elite oarswomen average 173 centimeters in height, weigh an average of 70 kilograms, and range between 12% and 25 % body fat (Clarkson et al., 1983; Hagerman et al., 1979). Lightweight oarsmen tend to be very tall and lean, having only 7% to 8 % body fat( Hagerman, 1984).

## Testing Apparatus

Bicycle ergometers were the earliest testing apparatus used to evaluate physiological response during exercise in oarsmen (Agnerik et al., 1967; Nul et al., 1966; Nowacki et al., 1969, 1971a,b; Saltin and Astrand 1967; Yamakawa and Ishiko, 1966). Graded exercise tests where  $\dot{V}O_2$  max was achieved at the end of exercise were used in many bicycle ergometer

tests (Agnervik et al., 1967; Astrand, 1967; Nowacki et al., 1969, 1971a). This testing procedure using the bicycle ergometer as the testing apparatus was the method used on most highly trained athletes, regardless of the specific sport in which the athlete competed.

The measure of physical working capacity in oarsmen using a rowing ergometer was first introduced in 1971 (Hagerman and Lee, 1971). A mechanically braked rowing ergometer was used in most of the studies done in the United States because of its mechanical operation and task specificity (Harrison, 1967; 1970). A six minute test protocol was the designed exercise test in many of the early studies (Hagerman and Lee, 1971; Hagerman, 1975; Hagerman et al., 1972, 1975a, 1978; G. R. Hagerman, 1976). This design was used as it closely simulates rowing on 8 oared boat over the standard 2000 meter distance. A three minute protocol was later designed and used to simulate a 1000 meter race, usually rowed by women (Hagerman et al., 1979) in international regattas.

In more recent studies, (Hagerman and Mickleson, 1981; Mahler, 1983; Mahler et al., 1983; Mickleson and Hagerman, 1982) a variable wind resistance rowing ergometer (Concept II, Morrisville, VT) replaced the fixed resistance rowing ergometer explained by Hagerman et al. (1978) as the testing apparatus. The majority of experienced oarsmen and oarswomen pick the Concept II as the ergometer that best simulates actual rowing. Studies have been done recently on the Concept II, to calculate power output relative to velocity and stroke rates performed during various intensities and durations of work (Hagerman and Mansfield, 1984).

The studies performed on the rowing ergometer produced slightly higher maximal aerobic capacity than these bicycle ergometer studies

(Agnervik et al., 1967; Astrand, 1967; Nowacki et al., 1969, 1971a). Localized muscular fatigue prior to the attainment of maximal working capacity has been the primary reason given for the depressed  $\text{VO}_2$  max values in cycle ergometry. Due to the nature of the six minute test most often used, peak  $\text{VO}_2$  max values were often recorded between the second and fourth minutes of exercise, rarely in the fifth, and never in the sixth and final minute of exercise (Hagerman et al., 1979; Mahler et al 1984).

Some studies have utilized a graded treadmill exercise test to exhaustion and found  $\text{VO}_2$  max values equaled the highest  $\text{VO}_2$  measured during simulated rowing (Carey et al., 1974; Hagerman et al., 1975b). The differences in oxygen utilization in these types of tests have been attributed to differing total muscle masses involved (Hagerman, 1985). Though both rowing and cycling are weight supporting exercises involving extensive quadriceps muscle group action, treadmill running and rowing use the hamstring group to a greater extent (Hagerman, 1984).

This attainment of physiological peak closely parallels those found in recent six minute rowing ergometry studies and brings to question the unique pattern of pacing that rowers use during competition.

### Power Output

Power output has been estimated for actual rowing (Celentano et al., 1974; DiPrampo et al., 1971; Jackson and Secher, 1976; Orfelt, 1970; Secher, 1983) and measured during simulated rowing (Connors, 1974; Hagerman, 1975; Hagerman and Howie, 1971; Hagerman and Lee, 1971; Hagerman et al., 1972, 1975a, 1978, 1979; G. C. Hagerman, 1976; Polinski,

1976; Williams, 1976). Secher (1983) reported a power output of 386 watts at racing speed in the direction of the boat, and 471 watts total, including work in the transverse direction because of the biomechanical nature of the rowing stroke. Lightweight men and women have power outputs somewhat less than those of elite heavyweight oarsmen. An average of 370 watts has been reported during a six minute simulated exercise in lightweight men and an average of 300 watts for women was recorded during 3 minutes of simulated rowing (Hagerman et al. 1979). Hagerman reported average power outputs of 20 U. S. National Team members to be 390 watts with values ranging from 360 to 421 watts during six minute simulated rowing exercise.

### **Mechanical Efficiency**

Mechanical efficiency has ranged from 10% to 25% during simulated rowing (Connors, 1974; Cunningham et al., 1975; DiPrampo et al., 1971; Hagerman et al., 1978, 1979; Jackson and Secher, 1976; Secher, 1983) and from 16 to 24% in actual rowing (Cunningham et al., 1975; DiPrampo et al., 1971; Harrison, 1970; Secher, 1983). These findings of similarities in actual rowing and simulated rowing mechanical efficiencies support the use of rowing ergometry to adequately represent the task of rowing.

### **Evaluating Energy Costs**

The measurement of human energy expenditure at rest and during physical activity has been of great interest over the years to scientists and athletes alike. Energy expenditure, or heat production has been measured in

two ways; direct calorimetry and indirect calorimetry.

Direct calorimetry involves placing subject to be tested inside an air tight, thermally insulated chamber where heat production during the subjects activity can be evaluated. This method, though highly accurate, is impractical for evaluating energy costs during various sports, recreational, and occupational activity. Indirect calorimetry is almost always the method used in these cases.

Indirect calorimetry is based on the fact that all energy metabolism depends on the utilization of oxygen. Thus, by measuring an individual's oxygen consumption, an indirect estimate of energy metabolism can be obtained. Direct calorimetry studies have shown that approximately 4.82 kcal of heat are produced when a mixture of protein, carbohydrate, and fat is burned in one liter of oxygen. This value varies only slightly with even large variation of metabolic mixtures used as the energy source. For convenience of calculation, the value of 5 kcal per liter of oxygen has been used for the indirect method of energy expenditure during studies involving all types of activity and exercise (McArdle et al, 1981).

### **Aerobic Importance**

Studies during acute and chronic hypoxic exposure have magnified the importance of high levels of aerobic capacity to an oarsmen's performance (Hagerman, 1969; Hagerman et al., 1975b). More dyspnoea-hypoxia related physical collapses were reported during the rowing competition at the 1968 Olympic games in Mexico City than for any other aerobic type event or sport. More than 80 incidents of physical collapse by oarsmen in the first 2 days,

and several more during later races were reported by rowing officials in Mexico City (Hagerman, 1969). Complete cessation of a crew during competition is extremely rare in International Regattas and if so, is usually due to mechanical difficulties. Several crews in Mexico City stopped frequently and some failed to finish races at the 1968 Olympic Regatta. Hagerman et al., (1975) also reported significant effects on ventilatory adaptation in oarsmen following acute and chronic exposure to moderate altitude.

### Pacing Strategies During Rowing

Men's 2000 meter competitive race rowing has been previously established to be a predominately aerobically based exercise with aerobic metabolism yielding 75% to 85% of the total energy cost (Connors, 1974). Given this energy demand, a physiologically sound and efficient racing strategy would presumably be employed. Ironically, this has not been the case. Traditionally, oarsmen have violated the recommended methods of pacing for endurance events: a steady aerobic workload over the majority of the race with an anaerobically based sprint over the final 45 to 60 seconds of the race (Hagerman et al. 1979; Mahler et al. 1984). During traditional race rowing, oarsmen begin races at extremely high energy expenditures and marked anaerobic response for the first 30 to 45 seconds before they settle at a slower steady rate of performance for the middle four to five minutes of the race. This is followed by another anaerobically based sprint over the last 45 to 60 seconds (Hagerman et al., 1972; Hagerman et al., 1979). Race rowing split times show the first 250 meters to be the fastest, with the



following 250 meter segments covered in equal slower times with the last 250 meters being slightly faster (Hagerman et al., 1979). This strategy put a great stress on the oxygen transport system and increases anaerobiosis (Hagerman et al., 1972), which produces maximal lactate levels at the start of the race. These lactate levels must be endured for the duration of the race while inhibiting aerobic performance (Hagerman et al., 1972).

### **Aerobic Metabolism of Oarsmen**

Limited research was conducted with oarsmen during the 1920's (Henderson and Haggard, 1925; Liljestrand and Lindhard, 1920), and not until the late 1960's did physiological data of oarsmen and oarswomen begin to appear in scientific literature (Astrand, 1967; Astrand and Rodahl, 1977; Hagerman, 1969; Hamby and Thomas, 1969; Hay, 1968; Ishiko, 1967; Mollerowicz and Hansen, 1965; Nowacki et al., 1969; Saltin and Astrand, 1967). In 1967, high levels of aerobic capacity were reported in Swedish oarsmen performing on bicycle ergometers (Astrand, 1967). The average of these high levels of aerobic capacities ranked these oarsmen behind only biathletes, cross country skiers, and orienteering athletes. Saltin and Astrand (1967) studied the effects of maximal treadmill running and bicycle ergometry work on  $\dot{V}O_2$  and heart rate in several highly conditioned athletes from the sports of canoeing and rowing. These subjects performed both arm and leg exercises on a specially designed bicycle ergometer. The oarsmen's maximal  $\dot{V}O_2$  in liters per min compared favorably with the results achieved by the canoeists, cyclist, middle distance runners, and biathlon competitors,

all achieving an average  $\text{VO}_2$  max of 5.1 to 5.4 liters per minute. When oarsmen's  $\text{VO}_2$  max was expressed in relative terms, milliliters per kilogram per min (ml/kg/min), an average of 62 ml/kg/min was obtained. This value was well below the mean values achieved for other endurance type athletes, reportedly due to consistently greater body weights in the oarsmen.

### Absolute and Relative Values

Numerous studies have shown that maximal aerobic capacities of elite oarsmen and oarswomen are among the highest recorded (Di Prampero et al., 1970; Hagerman and Lee, 1971; Hagerman et al., 1972, 1975a, 1978, 1979; Jackson and Secher, 1973, 1976; Larson and Forsberg, 1980; Mahler et al., 1983, 1984; Nowacki et al., 1969, 1971a; Saltin and Astrand, 1967; Secher, 1983; Secher et al., 1982). Absolute  $\text{VO}_2$  max values have been measured in excess of 7 liters per minute (l/min) in 2 elite oarsmen, and over 5 l/min in 3 females (Hagerman et al., 1979). Translated to relative terms these values were over 80 ml/kg/min for the men and over 70 ml/kg/min for the women. Lightweight oarsmen have attained the highest relative  $\text{VO}_2$  max with values exceeding 80 ml/kg/min (Hagerman et al., 1979). Due to their body size and total muscle mass, lightweight oarsmen would be expected to achieve this greater  $\text{VO}_2$  max in relative terms while at the same time not reaching the absolute values achieved by heavyweight oarsmen.

Metabolic data collected on more than 2000 oarsmen and oarswomen

with international experience appears to indicate that if rowing athletes expect to become successful at this level, males should be able to achieve a  $\text{VO}_2$  max of 6 l/min while females should be able to achieve a  $\text{VO}_2$  max of 4 l/min (Hagerman, 1984).

The fact that oarsmen's and oarswomen's weight is supported in the boat, seems to point toward absolute  $\text{VO}_2$  max as the more relevant of the two measurements of oxygen uptake. The German Democratic Republic uses such an objective criterion to assist in identifying athletes with outstanding physiological capacities ( FISA Coaches Conference Report, Rome, Italy, October 1980). Athletes from East Germany must be able to attain a  $\text{VO}_2$  max of 6 l/min and 4 l/min for men and women respectively to be considered for national team selection. This selection process attempts to identify those athletes having one of the major components attributed to international rowing success; a highly developed oxygen transport and delivery system.

### Oxygen Consumption During Rowing

Oxygen consumption in rowers parallels the demands of the athlete on the oxygen transport system as is the case in all physical events. A careful examination of the aerobic curve in oarsmen shows a unique response to a predominately aerobic event. With the exception of the first minute of exercise, oarsmen perform at near maximal aerobic capacities for the entire duration of a six minute exercise test (Hagerman et al. 1979). The largest portion of a very high oxygen deficit is incurred during the first 30 to 90

seconds of exercise after which they must call on their highly developed aerobic capacities to meet the energy requirements of the next four minutes (Connors, 1974; Hagerman et al., 1978; G. C. Hagerman, 1976; Polinski, 1976). Anaerobiosis is called upon over the last 30 to 60 seconds when a boat's final all-out sprint to the finish occurs. This approach appears to elicit a rather inefficient approach to energy production.

An estimated oxygen cost of 46 liters was reported by DiPrampo et al., (1971) for rowing a paired boat over 2000 meters. This value was obtained during tank or basin rowing where water and current conditions are often less than optimal (Hagerman and Lee, 1971). Oxygen consumption during actual rowing was reported by Jackson and Secher (1976) with average  $\text{VO}_2$  values of between 5.8 and 6.0 liters per minute for a paired-oared crew during 7 to 8 minutes of strenuous work. These values supported the results of DiPrampo et al. (1971) but were somewhat higher than those aerobic values reported by Hagerman et al. (1984) in which a rowing ergometer was used. The relatively greater amount of work required during paired rowing as opposed to eight oarsmen sharing the work load may explain these oxygen cost differences. It is also possible that the rowing ergometer slightly underestimates an oarsman's maximal aerobic capacity. Differences in boat length, weight, and design have all been mentioned as important factors that may alter an oarsman's energy production.

## Aerobic Capacities

Studies on the aerobic capacities of rowers have consistently put them

among the elite athletes in terms of achieving extremely high maximum  $\text{VO}_2$  values. Although this measure of  $\text{VO}_2$  max is helpful in assessing athletic potential and performance, rowers' most impressive physiological attribute seems to be their ability to sustain extremely high percentages of their absolute  $\text{VO}_2$  max even after they have exceeded their anaerobic threshold levels (Hagerman et al., 1978).

### Energy Costs of Rowing

$\text{VO}_2$  and velocity measurements of an elite paired-oared crew were used to calculate the metabolic cost of rowing at racing speed. An average of 6.38 liters/minute was reported (Jackson and Secher, 1973;) An oxygen cost continuum every ten years for race rowing from 1919 to 1979 was later shown using this same data (Secher, 1983). Oxygen cost was reported to increase from a level of 5.1 liters/ minute in 1919 to 6.38 liters/minute in 1979. In 1925, Henderson and Haggard had estimated 6.1 liters minute as the oxygen cost of rowing a competitive race. This value is equivalent to about 30 kcal/minute. Three energy yielding systems; aerobic, anaerobic-alactic, and anaerobic lactic along with their relative energy contributions to rowing were studied by Connors, 1974. Energy contributed by the aerobic energy system was calculated from the net exercise  $\text{VO}_2$  measured during a six minute rowing ergometer test. Connors reported that 77.8% of the total energy expended during the six minute exercise was supplied by aerobic means. R-values were used to estimate the relative kcal equivalent of

oxygen consumption.

Mangaria's formula (Mangaria et al., 1963, 1964) was applied to post-exercise venous blood lactic acid concentrations and indicated that glycolysis provided 4.1 kcal/minute or 13.8% of total energy expenditure. Secher (1983) proposed a similar percentage of 14% attributed to anaerobic metabolism.

## Heart Rate

Maximal heart rates for both men and women during simulated and actual rowing are similar and average between 190 and 200 beats/minute (Hagerman and Lee, 1971; Jackson and Secher, 1976; Secher et al., 1982). Heart rates have been successfully measured during training and competition (Hagerman and Lee, 1971; Ishiko, 1968; Jackson and Secher, 1976; Pruett, 1977; Schneider, 1980). Oarsmen have averaged between 180 and 190 beats/minute for 6 to 8 minutes of exhaustive rowing (Cunningham et al., 1975; Hagerman, 1975; Hagerman and Howie, 1971; Hagerman and Lee, 1971; Hagerman et al., 1972, 1975a, 1978, 1979; Ishiko, 1968; Nui et al., 1966; Secher, 1983; Williams, 1976). Heart rates have been monitored throughout progressive tests to determine anaerobic threshold heart rates. Rates of 160 to 170 have been consistently observed (Hagerman and Mickleson, 1981; Mahler, 1983; Mahler et al., 1983; Mickleson and Hagerman, 1982). These results would be useful in more accurately planning and monitoring training sessions so that the desired physiological training stimulus might be achieved.

## Breathing Frequency

Breathing frequencies generally average at least 60 breaths/minute during both actual and simulated rowing. Peak levels of 80 to 85 breaths/minute have been recorded in some athletes (Hagerman et al. 1984). Oarsmen appear to use cyclic breathing and breathe at least twice during the cycle of each complete rowing stroke.

## Pulmonary Ventilation During Rowing

Significant elevations in ventilation have accompanied the increases in oxygen uptake during simulated rowing. Measurements in excess of 240 liters/minute BTPS have been reported and excluding the first minute of exercise, most oarsmen average 200 liters/minute BTPS during both six minute ergometer rowing or actual rowing for the same time (unpublished data, Work Physiology Laboratory, Ohio University). Cramped body position of oarsmen during the catch phase of the rowing stroke has been suggested as the reason for a reduction of ventilatory equivalent ( $V_E/VO_2$ ) in oarsmen (Cunningham et al., 1975). Others have found no evidence to indicate a reduction of breathing frequency or an impairment of pulmonary ventilation (Clark et al., 1983; Hagerman, 1975; Hagerman et al., 1972, 1975a, 1978, 1979).

## Anaerobic Threshold Limits

A graded exercise protocol on the rowing ergometer has been used in



recent studies for the purposes of determining both anaerobic threshold and  $\dot{V}O_2$  max. Graded exercise testing allows for a gradual increase in metabolic and cardiorespiratory activity. This gradual increase allows detection of the point where exercise intensity begins to exceed the capacity of the oxygen delivery system to sustain exercise. This progressive incremental exercise test allows the athlete to continue exercise in a stepwise fashion until  $\dot{V}O_2$  is reached, sometime after the observation of the anaerobic threshold.

Anaerobic threshold, or an increase in anaerobiosis, has most often been defined as the point in a graded exercise test at which there is a non-linear increase in  $\dot{V}_E/\dot{V}O_2$ , while  $\dot{V}_E/\dot{V}CO_2$  remains unchanged (Wasserman, Whipp, Kayal, and Beaver, 1973). This progressive incremental testing procedure has also elicited  $\dot{V}O_2$  max results similar to the maximum or peak values of  $\dot{V}O_2$  recorded during three and six minute rowing ergometer tests designed to simulate race conditions and not just an acceptable anaerobic measure of anaerobic threshold (Hagerman and Mickleson, 1981; Mahler, 1983; Mahler et al. 1983; Mickleson and Hagerman, 1982).

A great deal of controversy still surrounds the accuracy and meaning of anaerobic threshold measurements. Recent studies (Hagerman and Mickleson, 1981; Mahler, 1983; Mahler et al., 1983; Mickleson and Hagerman, 1982) have reported anaerobic threshold measurements that are indeed estimates, but never the less provide useful information to athletes and coaches alike to better evaluate relative fitness levels and to determine training intensities. Anaerobic thresholds of 85% to 95% of  $\dot{V}O_2$  max (Hagerman and Mickleson, 1981; Mahler, 1983; Mahler et al., 1983; Mickleson



and Hagerman, 1982) attest to the very high aerobic capacities of rowing athletes.

Anaerobic threshold measurements are most commonly reported as a percentage of  $\dot{V}O_2$  max. In studies performed on oarsmen during the off season, measurements were significantly lower, 70% to 75%, than those measurements taken only weeks before the World Rowing Championships, when they were reported at between 85% and 95% of  $\dot{V}O_2$  max (Hagerman and Mickleson, 1981; Hagerman and Staron, 1983; Mickleson and Hagerman, 1982). In terms of enhancing performance, the increase in oxygen utilization could delay the possible deleterious side effects of increasing lactic acid during high intensity exercise (Astrand and Rodahl, 1977; Hagerman et al., 1978). An increased ability to utilize lactic acid as a fuel for exercise may be an important attribute of the endurance trained athlete with high anaerobic thresholds (Orfelt, 1970; Spitzer, 1974). Utilization of lactic acid during a six minute rowing ergometer test reported by Hagerman et al., (1978) was proposed since there was either a slight reduction or no change in this variable from its peak concentration at the second minute of exercise until cessation of exercise, despite significant involvement of the anaerobic energy system.

### Energy Contribution of Anaerobic Metabolism

Aerobic metabolism as expressed by oxygen uptake is a highly reliable measurement and has been reported extensively in numerous studies. Anaerobic metabolism, on the other hand, is extremely difficult to assess.

This relative contribution of anaerobic metabolism to rowing has been estimated in a number of ways including the measurement of oxygen deficit, oxygen debt, and the energy equivalent of post-exercise lactate concentrations (Connors, 1974; Hagerman et al., 1974, 1978; G. R. Hagerman, 1976; Polinski, 1976). Consensus of theory would point toward oxygen deficit as being the best variable to represent anaerobic metabolism, but due to difficulties in accurate calculations most investigators have avoided this approach. Reported oxygen deficits have varied greatly and seem questionable. Values ranging from 6 to 8 liters for both oarsmen and oarswomen were reported by Hagerman et al. (1979) while Secher et al. (1982) have reported larger values. Oxygen debts, however, were somewhat higher and based on measuring  $\dot{V}O_2$  for a 30 minute period following a six minute and three minute simulated rowing exercise for men and women respectively. Hagerman et al. (1978) reported Oxygen debts as high as 20 liters for international caliber oarsmen with an average of 13.5 liters. Secher et al., (1982) reported a maximal value of 33 liters. Oxygen debts measured on oarswomen and lightweight men have been reported as 10 and 12 liters respectively (Hagerman et al. 1979).

Blood lactate levels also signify anaerobic energy involvement. Maximum venous blood lactate concentrations have been reported to range from 14 to 18 mmol/liter following six minute simulated rowing in both elite lightweight and heavyweight oarsmen. Exhaustive treadmill running produced 11 mmol/liter in oarsmen and a range of 15 to 17 mmol/liter was seen immediately after national and international rowing competition (Vaage, 1977). Concentrations for women averaged 16 mmol/liter following three minutes of simulated rowing (Hagerman et al., 1979). These high

levels of blood lactate concentrations signify significant anaerobic energy involvement during competitive rowing.

### **Carbon Dioxide Production**

Carbon dioxide is a direct bi-product of the chemical chain reaction involved in energy liberation and utilization. With increasing amounts of energy expenditure, an increasing amount of carbon dioxide is produced. This carbon dioxide must be transported to the lungs where the exchange of carbon dioxide and oxygen takes place. Oxygen is consumed for sustained energy production as carbon dioxide is released and exhaled to the outside atmosphere.

Carbon dioxide production can be a useful tool in monitoring energy releasing chemical reactions during exercise. The greater amount of carbon dioxide an individual produces reflex a greater amount of energy producing chemical reactions taking place within the individual.

## CHAPTER III

### METHODOLOGY

#### Subjects

Ten members of the University of Rhode Island's 1984-85 men's lightweight crew team volunteered to participate in this study. These subjects were the eight members that comprised the boat which won the 1984 Dad Vails Regatta, making them national small college champions, and two alternates. Prior to any testing, subjects were given a brief explanation of the study and its purpose.

#### Study Design

All testing was performed during the third week of February, 1985, in the Human Performance Laboratory at the University of Rhode Island. All subjects were given a general overview of the procedures prior to the initiation of any testing. Hypothesis and specifics of testing protocols were not discussed with the subjects. Prior to their first exercise testing session, subjects were scheduled for body composition assessments. Hydrostatic weighing was the technique employed.

When subjects arrived for their first exercise testing session, they were asked to read, complete, and sign an informed consent statement and a

verbal medical history evaluation was performed. Each subject's height and weight were then taken and recorded just prior to being prepared for a CM-5 EKG configuration. Resting heart rate and blood pressure were measured and recorded.

Forty eight hours after each subject completed his first testing session, he returned to perform the second exercise test. Times were kept consistently forty eight hours apart with individuals having identical testing circumstances on each day. All subjects completed the same training sessions during the testing week.

### Testing Protocols

On the first visit to the Human Performance Laboratory, each subject performed the first of two distinctly different exercise tests on the Concept II rowing ergometer. This "all-out" (AO) test was designed to simulate the duration, intensity, and racing strategy of a competitive 2000 meter rowing race. This (AO) protocol was a modified version of the "all-out" protocol described by Mahler et al. in the December 1984 issue of Medicine and Science in Sport and Exercise.

Each subject performed a five minute warm up on the Concept II rowing ergometer at a flywheel speed of twenty-two mph, (35 kpm). After this warm up, each subject was given a five minute rest as he received instructions from his coxswain on the exercise test that would follow.

Each subject was coaxed through his customary start from the stationary position of 3/4 slide, 1/2 slide, 3/4 slide, 4/5 slide, 5/6 slide, full slide, followed by 20 full strokes of maximal effort at a stroke rate

cadence of 36 strokes per minute. The stroke rate was then reduced to a cadence of 30 strokes per minute until the three mile mark, where the subject was coaxed for his final all-out sprint over the last .5 mile.

After a forty eight hour period, in which all subjects completed the exact training sessions, subjects returned to perform the second exercise testing protocol. This Pacing (P) protocol was designed to follow the generally employed strategy in most exercise events of the aerobic type.

Each subject again performed a five minute warm up on the Concept II rowing ergometer at a flywheel speed of twenty-two mph, (35 kpm). After this warm up, the subject was given a five minute rest as he received instructions from his coxswain on the exercise test that would follow.

Each subject was again coaxed through his customary start from the stationary position of 3/4 slide, 1/2 slide, 3/4 slide, 4/5 slide, 5/6 slide, full slide, followed by 20 full strokes of maximal effort at a stroke rate cadence of 32 strokes per minute. The stroke rate was then reduced to a cadence of 31 strokes per minute until the three mile mark, where the subject was coaxed for his final all-out sprint over the last .5 mile.

Two sets of power ten strokes were also performed by each oarsmen in each exercise testing protocol. These power tens were done at a cadence of two strokes per minute faster than the settle stroke rate in the body of the given protocols, or at 32 strokes per minute in the "all-out" protocol and 33 strokes per minute in the pacing protocol. These strokes were done at the 1.5 and 2.3 mile marks in each of the two protocols which simulates closely the points in a rowing race where power tens are usually performed.

### Derived Measurements

Derived measurements include percent body fat from hydrostatic weighing and stroke rate from stroke watch reading.

### Physical Measurements

Height was recorded to the nearest quarter of an inch, and weight was recorded to the nearest quarter of a pound on a physician's scale.

Percentage of body fat was evaluated with the hydrostatic weighing procedure described by Katch and Katch, 1984. (Appendix A ) This procedure was performed in the Tootell Aquatics Center utilizing the competitive diving pool as the underwater weighing tank.

### Physiological Measurements

Physiologic and metabolic data were obtained using the Erich Jaeger Ergo Pneumotest equipped with a Hewlett Packard Data Spir Junior. The gas analyzer is equipped with a two-way modified Wilmore-Costill breathing valve, oxygen and carbon dioxide analyzers, a pneumotacograph for volume measurements, and a computer assisted assembly for on line thirty second metabolic calculations of absolute oxygen consumption ( $\dot{V}O_2$ ) , relative oxygen consumption ( $M\dot{V}O_2$ ), minute volume ( $\dot{V}_E$ ), volume of carbon dioxide produced ( $\dot{V}CO_2$ ), respiratory quotient (RQ), breathing frequency (BF) and fractions of expired oxygen ( $F_{EO_2}$ ), and carbon dioxide( $F_{ECO_2}$ ). Prior to

the rowing ergometry tests, the gas analyzers were calibrated with a known quantity of gas (% CO<sub>2</sub>=3.81, % O<sub>2</sub>=15.92) determined via the Scholander technique (Scholander, 1947). Periodic gas samples were tested between subjects to check the stability of the calibration.

Testing conditions at the Human Performance Laboratory were moderate with an average (+ - standard deviation) temperature of 22.1 + - .8 C and humidity 49% + - 4%. All gas volumes were converted to standard temperature, pressure, and dryness (0 C, 760 mmHg, 0% humidity) for metabolic calculation (Katch et al., 1981).

### Actual Performance

Rowing performance was measured as the elapsed time to complete two 3.5 mile rowing tests performed on the Concept II rowing ergometer. Subjects performed tests individually in the laboratory setting while a coxswain provided verbal stroke cadence and laboratory assistants collected test data.

### Statistical Analysis

All data that were collected in the study were key punched and processed at the Academic Computer Center at the University of Rhode Island. Paired T-tests were performed between the same testing variables on different testing days. The formula for the dependent T-test is

$$t = \frac{\bar{D}}{\sqrt{\frac{\sum D^2 - \frac{(\sum D)^2}{N}}{N(N-1)}}$$

where

t = the t-value for dependent means

D = the difference between the paired scores

$\bar{D}$  = the mean of the differences

$\sum D^2$  = the sum of the squared difference scores

N = the number of pairs



Means and standard deviations were also calculated to determine scores rankings.

### VARIABLES TESTED

The following variables were tested:

#### Physiological Variables

- Maximal oxygen consumption ( $\text{VO}_2 \text{ max}$ )  
(liters . min<sup>-1</sup>)
- Maximal oxygen consumption (ml . kg<sup>-1</sup> . min<sup>-1</sup>)
- Ventilatory equivalent
- Minute volume
- Respiratory Quotient
- Breathing frequency
- Heart Rate

#### Performance Variables

- Performance Time (min:sec)
- Stroke Rate

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Descriptive Statistics

##### Physiological Characteristics

The mean physical characteristics of subjects are presented in Table 1. When compared to 12 candidates for the 1983 United States Men's Lightweight Rowing Team (Mahler et al., 1984), subjects in the present study tended to be slightly shorter and heavier, with Mahler et al. (1983) reporting an average height of  $183 \pm 3$  cm and weight of  $72.2 \pm 1.4$  kg. The percentage of body fat of the subjects in this study was higher (11.26%) when compared to the 7 to 8 percent reported by Hagerman et al., (1984) and the 8.5 percent reported by Burke (1980) for lightweight oarsmen. Subjects tested in the present study were tested in the off season and were not in peak condition. This may explain some of the difference between group scores in percentage of body fat. Hagerman and Staron (1983) found elite oarsmen to have quite extreme seasonal variations across all physiological variables.

##### Testing Times

Table 2 reports the mean group scores of total time taken to complete the "all-out" and pacing exercise tests. The group average for the completion of the 3.5 mile rowing ergometry test employing the all-out strategy was  $6' 19.6" \pm 8.13"$ . The group average for total time when subjects employed the pacing strategy was  $6' 20.3" \pm 8.31"$ . As these times

TABLE 1

## PHYSICAL CHARACTERISTICS

SUBJECT	AGE	HEIGHT(CM)	WEIGHT(KG)	% BODY FAT
1	21	177.80	79.55	14.80
2	21	185.42	75.23	11.31
3	21	180.34	71.82	9.86
4	20	182.88	73.41	10.99
5	21	180.34	75.68	10.40
6	25	179.07	78.86	7.90
7	21	175.26	71.48	13.50
8	22	180.34	76.36	9.97
9	19	175.26	66.48	8.21
10	19	171.45	69.09	15.70
MEAN	21	178.82	73.80	11.26
S.D.	1.7	4.10	4.20	2.60
COEFF	6	13.97	13.07	7.80

TABLE 2

GROUP MEAN STROKE RATES AND PHYSIOLOGICAL VALUES  
OVER COMPLETE AO AND P PROTOCOLS

	<u>AO</u>	<u>Sd+-</u>	<u>P</u>	<u>Sd+-</u>	<u>P&lt;</u>
<u>STROKE RATE (S/MIN)</u>	30.6	1.17	31.7	.949	.01
<u>HEART RATE (BEATS/MIN)</u>	177.6	7.70	173.0	6.65	.05
<u>VO<sub>2</sub> (L/MIN)</u>	4.29	.242	4.05	.315	.01
<u>VO<sub>2</sub> (ML/KG/MIN)</u>	58.63	3.70	55.01	3.69	.01
<u>TOTAL TIME (SECS)</u>	379.6	8.13	380.3	8.31	NS

report, a difference of only .7" was found between the group averages for the two protocols, demonstrating near identical performance times. These times are less than the 6' 36" reported as the median times obtained by the FISA regattas from 1974 to 1982 in the men's open class.

### Stroke Rate

Figure 1 shows the group mean stroke rates across each 30 seconds of the two testing protocols. Stroke rates for subjects performing the AO protocol were considerably higher during the first 30 seconds when compared to the rates over the first 30 seconds of the P test. Following similar rates recorded at the 60 second mark, subjects achieved and maintained higher stroke rates using the P protocol for the remainder of the test. Table 3 shows the group mean values of subjects' stroke rates across each 30 seconds of the two testing protocols along with the average stroke rates across all 30 second time periods. Also shown in Table 3 are probability values resulting from dependent T-tests applied to the two exercise tests.

During the first 30 seconds of each test, a significant difference was seen in the average stroke rates subjects attained performing the two testing protocols. Subjects averaged 36.7 strokes per minute (SPM) while performing the "all-out" test compared to 32.1 SPM during the first 30 seconds of the P test. At the 60 second mark, little difference was seen in the average stroke rates subjects achieved, with an average of 30.3 SPM achieved during the AO test and 31.2 SPM during the P test. This 60 second time period is where the cross over in protocols was designed, with subjects being coaxed to reduce their stroke rates from 36 SPM to 30 SPM

FIGURE 1

STROKE RATE

AO (—●—) AND P (—○—)

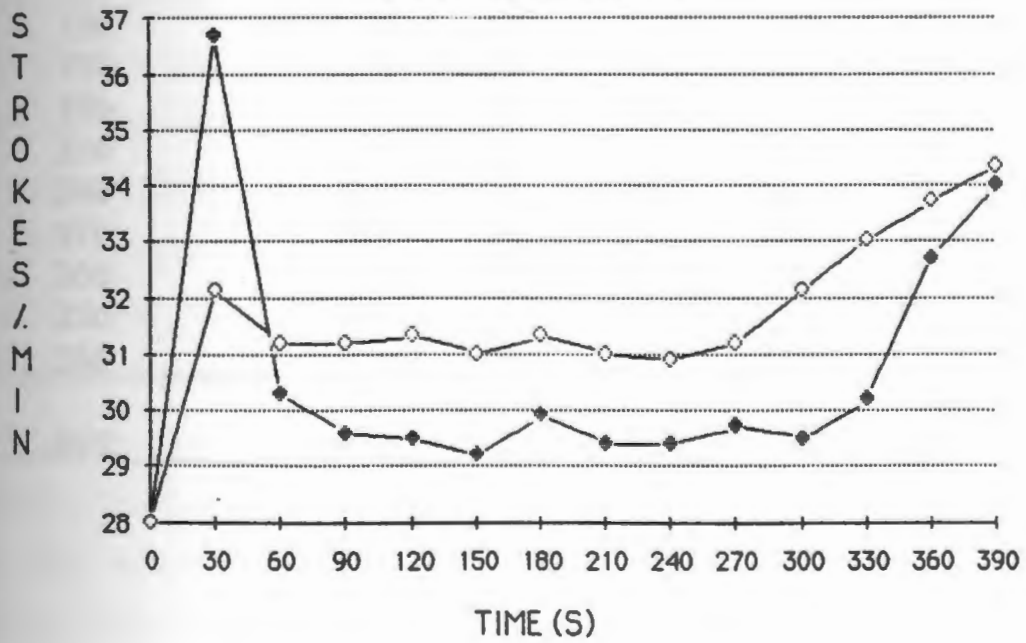


TABLE 3

STROKE RATE (strokes · min<sup>-1</sup>)

TIME (sec)	ALL-OUT	S.D.	PACING	S.D.	p
30	36.7	1.78	32.1	1.20	.01
60	30.3	2.11	31.2	.79	ns
90	29.6	1.09	31.2	.73	.01
120	29.5	1.18	31.3	.68	.01
150	29.2	1.23	31.0	1.05	.01
180	29.9	1.60	31.3	.82	.01
210	29.4	.84	31.0	.82	.01
240	29.4	1.08	30.9	1.10	.01
270	29.7	1.34	31.2	1.14	.01
300	29.5	1.35	32.1	1.29	.01
330	30.2	1.75	33.0	1.56	.01
360	32.8	1.48	33.7	1.00	ns
AVG	30.6	+ - 1.17	31.7	+ - .95	.01

in the AO protocol and from 32 to 31 SPM in the P protocol for the body of the test. After this cross over, subjects performing the P protocol achieved significantly higher stroke rates over each 30 second mark for the duration of the P test until the 360 second mark, where significance at the .05 level was barely missed. These differences were designed within the protocols prior to testing and show that distinct protocol differences were achieved. During the last .5 mile of each protocol, or approximately the last minute of the test, subjects were coaxed into their final sprint in which they were to perform at maximal effort until the 3.5 mile mark was achieved. During this time period, subjects performing the P test were able to increase their stroke rates faster and maintain this increased rate longer when compared to their AO test performance. Over the entire test, subjects averaged a greater stroke rate during the P test when compared to the AO test.

In summary, with the exception of the 60 second stroke rate scores, a significant difference at the .01 level was seen between all 30 second mean scores of the AO test when compared to the P test. Subjects attained a higher stroke during the first 30 seconds of the AO test, a similar stroke rate at the 60 second mark, and a significantly higher rate during the last 5 minutes of the P protocol. Subjects were able to maintain this higher stroke rate over the entire P test. Distinct protocol differences were designed and achieved within each of the two testing protocols.

### Heart Rate

Heart rate (HR) data were only collected on nine subjects. Figure 2 shows the group mean heart rate values across each 30 seconds of the two testing protocols. Heart rates recorded during the AO protocol were higher



**FIGURE 2**  
**HEART RATE**  
**AO (—●—) AND P (—○—)**

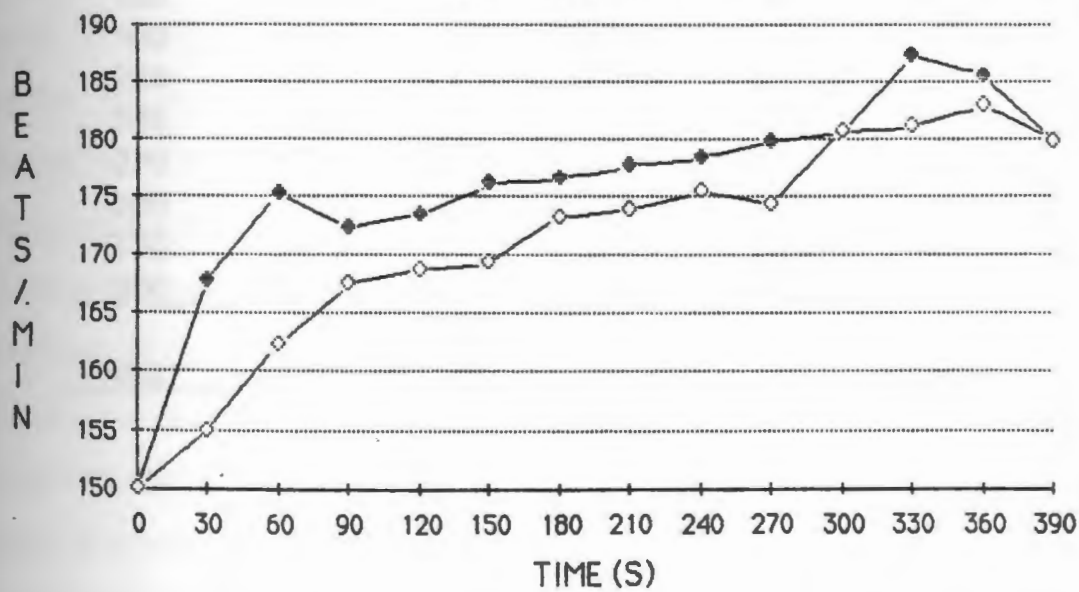


TABLE 4

HEART RATE (beats · min<sup>-1</sup>)

TIME (SEC)	ALL-OUT	S.D.	PACING	S.D.	p
30	167.8	14.01	156.0	12.00	.05
60	175.2	12.27	164.8	8.01	.05
90	172.2	9.19	168.9	6.07	.05
120	173.6	8.02	170.6	5.77	ns
150	176.2	8.09	168.6	8.62	.01
180	176.7	9.22	173.2	8.50	ns
210	177.8	7.61	175.2	6.78	ns
240	178.3	8.32	176.4	5.92	ns
270	179.9	9.20	174.4	8.13	.01
300	180.8	9.62	181.1	8.78	ns
330	187.2	10.01	182.1	9.29	ns
360	185.4	8.43	184.1	11.42	ns
avg	177.6 ± 7.70		173.0 ± 6.65		.05

at end of the first 30 seconds and remained higher over the entire AO test. Table 4 shows the group mean values of subjects' heart rate across each 30 seconds of the two testing protocols and average heart rate values across all 30 second time periods. Also shown in Table 4 are probability values between the subjects' performance on the two exercise tests.

The first 30 second scores show a significantly higher HR response during the AO test with subjects averaging  $167.8 \text{ beats} \cdot \text{min}^{-1}$  during the AO protocol and  $156.0 \text{ beats} \cdot \text{min}^{-1}$  during the P protocol. This is seen as the response to the significantly higher stroke rates reported during the first 30 seconds of the AO test. HR values remained higher throughout the entire AO test, reaching significance at the 150 second and 270 second marks. No significant differences were seen in HR's between the tests during the last 2 minutes. Group mean HR values across all 30 second scores over the entire test were significantly higher ( $p < .05$ ) in the AO test. These differences were seen despite the significantly lower stroke rates recorded during the AO protocol. When compared to the "all-out" and progressive incremental protocols performed by 12 members of the 1983 United States Men's Lightweight Rowing Team (Mahler et al., 1984), the heart rate responses of the subjects used in this study were very similar. During his AO test, Mahler et al. reported a mean heart rate value of  $177 \text{ beats} \cdot \text{minute}^{-1} \pm 7 \text{ beats} \cdot \text{minute}^{-1}$  was achieved during the first minute which gradually increased to  $183 \pm 6 \text{ b} \cdot \text{min}^{-1}$  by the sixth minute. Subjects in the present study responded similarly at the 1 minute mark with an average of 175.2 during the AO test which remained slightly higher with an average of 185.4 at the sixth minute.

In summary, the average HR recorded throughout the 3.5 mile AO protocol was significantly higher than the heart rate values recorded for the

P protocol. Mean group HR's were significantly higher throughout the first 90 seconds in the AO testing protocol and remained higher throughout the entire test. Averages across all 30 second scores for the entire test were also significantly higher in the AO test despite a significantly lower stroke rate performed during the AO test.

### Absolute Oxygen Consumption

Figure 3 shows the mean absolute oxygen consumption (VOL) for all ten subjects across each 30 seconds of the two testing protocols. Subjects consumed more oxygen over the first 30 seconds of the AO protocol and absolute oxygen consumption remained greater during the remainder of the AO test. Table 5 reports the group mean values of subject's absolute oxygen consumption across each 30 seconds of both testing protocols. Also reported in Table 5 are the probability values between the subject's performance on the two exercise tests.

The first 30 second scores show a significantly higher absolute oxygen consumption by subjects performing the AO protocol with mean values of 1.74 l/min and 1.50 l/min for the AO and P protocols, respectively. Absolute oxygen consumption values also remained higher throughout the duration of the AO protocol with values showing significance at the 60, 90, 120, 240, and 360 second marks. The significantly higher oxygen consumption throughout the first two minutes of the test is seen as a response to the significantly higher stroke rates performed during the first 30 seconds of the AO test.

In summary, the total oxygen cost to complete the AO test was significantly higher when compared to the P test. This oxygen consumption relates directly to energy production over the individual 30 second seg-

**FIGURE 3**  
ABSOLUTE OXYGEN CONSUMPTION  
AO (-●-) AND P (-○-)

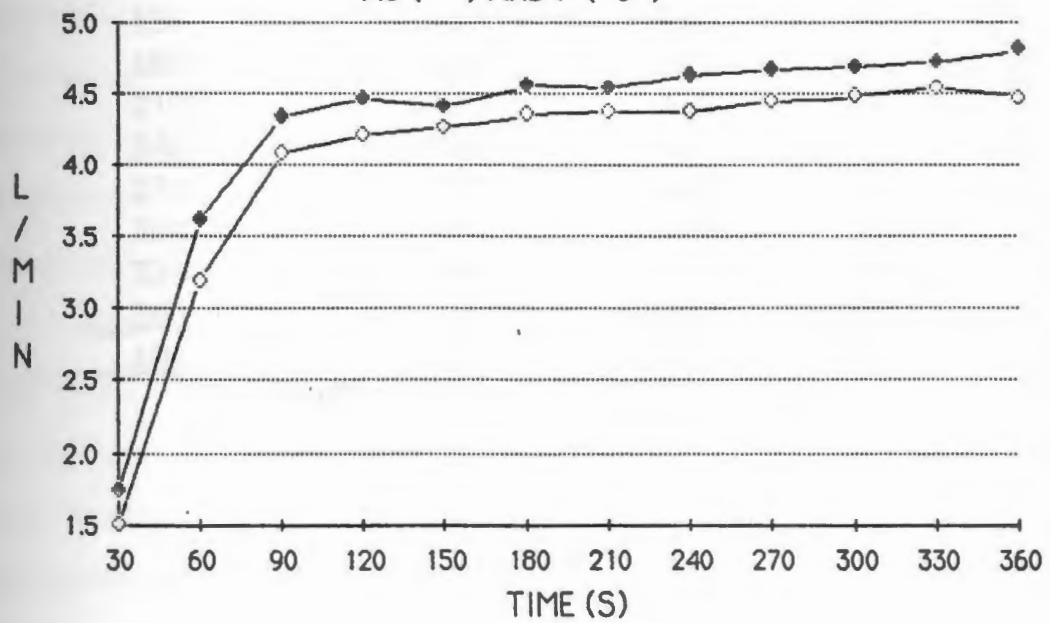


TABLE 5

ABSOLUTE OXYGEN CONSUMPTION (LITERS · MIN<sup>-1</sup>)

TIME (SEC)	ALL-OUT	PACING	P
30	1.74	1.50	.01
60	3.62	3.20	.01
90	4.33	4.07	.05
120	4.47	4.20	.01
150	4.41	4.26	ns
180	4.55	4.35	ns
210	4.53	4.37	ns
240	4.63	4.37	.01
270	4.67	4.45	ns
300	4.69	4.48	ns
330	4.73	4.54	ns
360	4.81	4.47	.05
AVG	4.29	4.05	.05

ments and for the entire exercise test. Therefore, where values of oxygen consumption are significantly higher, a significantly greater energy cost can be attributed to a given segment and to an entire exercise test. With the significantly higher absolute oxygen consumption reported for the AO protocol, this greater energy cost is seen.

### Relative Oxygen Consumption

Figure 4 shows mean relative oxygen consumption ( $\text{MVO}_2$ ) across each 30 second period for both exercise protocols. The subjects relative oxygen consumption was greater at the 30 second mark in the AO protocol and remained higher throughout the duration of the test. Table 6 reports the group mean relative oxygen consumption values across each 30 seconds of both the AO and P protocols. Also shown in Table 6 are the significant differences between the subject's performance during the two tests.

Subjects consumed significantly more oxygen relative to body weight during the first 30 seconds of the AO protocol with a mean value of 23.75 ml/kg/min compared to 20.29 ml/kg/min during the first 30 seconds of the P protocol. AO test values remained significantly higher through the first two minutes and at the 180", 240", and 360" marks. Mean relative oxygen consumption over the entire testing protocols was also significantly higher in the AO test.

In summary, when oxygen consumption was assessed in relation to subjects' body weight, subjects consumed a greater amount of oxygen, on average, in the AO test when compared to the P test. Subjects mean relative oxygen consumption was significantly greater during the first two minutes, between the 150' and 180' marks, between the 210' and 240' marks,

**FIGURE 4**  
 RELATIVE OXYGEN CONSUMPTION  
 AO (-●-) AND P (-○-)

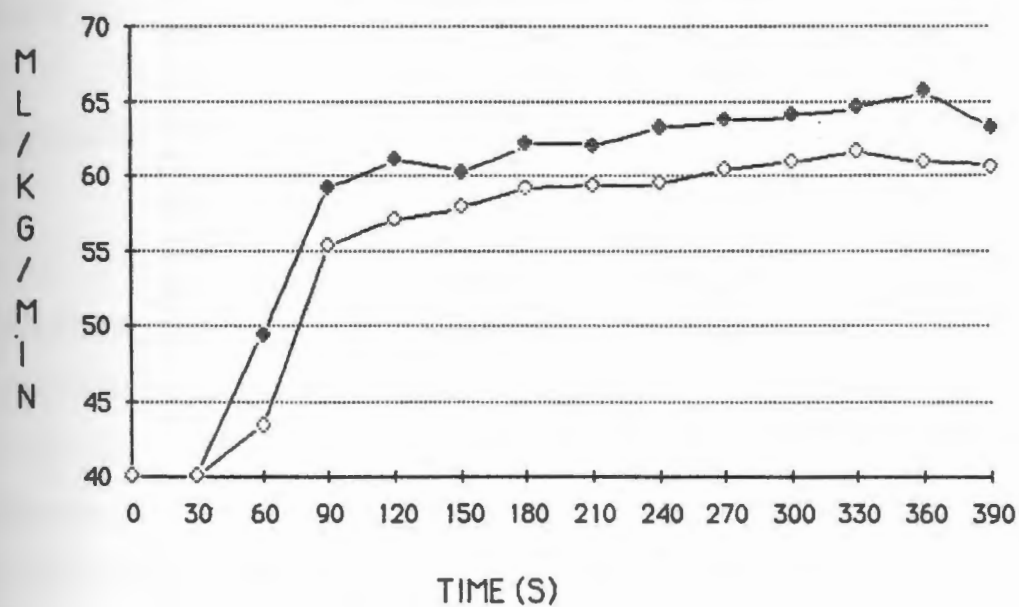




TABLE 6

RELATIVE OXYGEN CONSUMPTION (ML/KG/MIN)

TIME (SEC)	ALL-OUT	PACING	D
30	23.73	20.29	.01
60	49.31	43.46	.01
90	59.20	55.33	.01
120	61.12	57.15	.01
150	60.34	57.97	ns
180	62.10	59.22	.01
210	61.97	59.40	ns
240	63.26	59.50	.01
270			
300	64.10	60.94	ns
330	64.60	61.69	ns
360	65.65	60.91	.05
AVG	58.63	55.01	.01

and between the 270' and 300' marks of the AO test. This oxygen consumption relates directly to energy costs during individual 30 second segments, and total energy costs of the entire exercise test. Thus, more energy was utilized in completing the AO protocol than was used in the P protocol.

### Test of Hypothesis

#### Hypothesis I

Subjects will achieve a faster time while rowing 3.5 miles using the P protocol as opposed to the traditional AO protocol.

Table 6 reports the mean group scores of total time taken to complete both the AO and P exercise tests. The group average for the completion of the 3.5 mile rowing ergometry test employing the AO strategy was 6' 19.6"  $\pm$  8.13". The group average for total time when subjects employed the P strategy was 6' 20.3"  $\pm$  8.31". Though employing quite different testing strategies over the duration of the two testing protocols, the difference in total times taken to complete the 3.5 mile protocols were not significantly different. Therefore, hypothesis I was rejected.

#### Hypothesis II

Mean heart rates will be higher in subjects performing the AO protocol when compared to the P protocol.

Figure 2 and table 3 report the heart rate values for both protocols across same time periods along with total test averages during the two testing sessions. Subjects attained a higher rate immediately at the start of the AO test and maintained this higher rate throughout the duration of the AO test. The average of these scores across the entire tests was significantly higher for the AO test when compared to the P test and, therefore, hypothesis II was accepted.

### Hypothesis III

The average energy cost of the pacing protocol will be less than the AO protocol as measured by mean absolute and relative oxygen consumption.

Figures 3 and 4 along with tables 5 and 6 show absolute and relative oxygen consumption values across same time periods and total test averages. Consumption in both absolute and relative terms was higher at the initial 30 second calculation of the AO protocol and remained higher for the duration of the test when compared to the P protocol. Average consumption for the entire tests were also significantly higher in the AO test when expressed in both absolute and relative terms. Estimates of caloric costs determined by the methods described by McArdle (1981) require multiplying each liter of oxygen consumed by a constant of 4.82 kilocalories to estimate total energy costs of a given exercise. The understanding of this calculation allows us to conclude that a significantly greater amount of energy was consumed during the AO test. Therefore hypothesis III was accepted.

## Practical Implications

The purpose of the present study was to determine if the pacing strategy employed in the majority of aerobically based endurance events could be applied to the sport of race rowing where a unique pattern of racing strategy has evolved over the years. This strategy is often referred to as the "all-out" pace. Extremely high energy expenditures and elevated oxygen costs are demanded over the initial 30 to 45 seconds of the race followed by a slower steady rate performance level for the middle 4 to 5 minutes of the race, and finally an anaerobic sprint over the last 45 to 60 seconds of the race. The pacing strategies used in the majority of endurance events, which typically include a steady aerobic workload over the majority of the race with an anaerobically based sprint over the final 45 to 60 seconds of the race was what the P protocol in the present study simulated. Significant differences in stroke rates and selected physiologic responses were found between the two protocols. However, when considering performance over the 3.5 mile rowing ergometer tests, little difference was reported in times to complete the two exercise tests.

Absolute and relative oxygen consumption values were significantly higher over the first two minutes and on average for the entire AO test, which clearly indicate a higher metabolic cost for "all-out" performance. Subjects expended significantly more energy during the AO test without any advantage in actual performance. Conversely, the metabolic data suggests that the oarsmen "conserved" significantly more energy during the P test without any advantage in actual performance. At a glance, this finding seems contradictory. However, it should be noted that all subjects were

coaxed in the identical manner during the last minute of each test when they were instructed "all-out". During this time, the subjects performing the P test were able to increase their stroke rate more quickly as well as maintain higher stroke rates throughout the completion of the test.

From these observations it may be implied that the AO test or traditional approach did not elicit a favorable response from the subjects in that its start required too great an energy demand from which subjects never appeared to recover. This was demonstrated in the difficulty to increase and maintain a greater stroke rate over the last minute of the race. The strategy employed in the P protocol allowed the subjects to increase their stroke rates and maintain them until the 3.5 mile mark was reached. These data suggests that the stroke rates employed in the P protocol may not have been demanding enough to push each subject to his maximal performance. This "settled" rate of the P test may not have optimized the conditioning of these well trained athletes, leaving them with a greater energy reserve than necessary for the middle and final stages of the 3.5 mile row. A strategy employing the P tests make-up at a slightly higher "settled" stroke rate through the body of the test would allow for slightly faster stroke rates without the drastic changes employed in the traditional strategy.

The practical question facing researchers and coaches alike lies in how one can determine the proper pacing strategy to allow for optimal increases in the oxygen transport system without any effect of anaerobic metabolism. In many endurance events the anaerobic threshold is used to determine this point. However, due to the significant workload placed on oarsmen at the beginning of a race to get the rowing shell in motion, an anaerobic response

is inevitable in the first 1 to 2 minutes.

### Recommendations for Future Research

Race rowing, as in all other competitive racing events, poses the challenge to athletes and coaches alike to develop a racing strategy that will elicit optimal performance in the event of their choice. To this point, tradition, more than scientific knowledge and experiments has dictated the unique strategy employed by most elite oarsmen and rowing teams. The pattern of beginning races at extremely high energy expenditures along with a marked anaerobic response has remained the sport's trademark. The present study presents metabolic information which questions such an approach. Though subjects were unaccustomed to the P protocol in the present study and expended significantly less energy during this test, times for the P test were nearly identical to those achieved during the AO test. Conversely, subjects performing the AO protocol, a racing strategy that was familiar and practiced, had a metabolic cost which was significantly greater without any improvement in actual performance. Of interest to both the athlete and coach alike would be a similar study which employed a period of experimenting with stroke rates in an effort to find the optimal rate for the P test. This type of test would allow for the subjects to become familiar with a steadier race pace than they traditionally follow and may result in subjects "finishing strong" as opposed to "holding on" during the final minute of a rowing race.

A second study should include the training of oarsmen in the fashion presented by the present studies P test. By keeping the pacing strategy

relatively consistent and increasing the intensity across an entire training session or competition as subjects become more fit and not any particular portion of the race over the other portions, an oarsman would approach his training and performance in a more traditional and physiologically sound approach.

## **Conclusions**

- 1) A significantly higher stroke rate may be maintained during a 3.5 mile rowing ergometry test when using a pacing strategy as opposed to an "all-out" strategy.
- 2) Heart rates responses are significantly higher during an "all-out" rowing test of 3.5 miles when compared to a rowing protocol employing a pacing strategy.
- 3) Energy requirements as estimated from oxygen consumption are significantly higher during a 3.5 mile row employing an "all-out" strategy when compared to a pacing strategy.

## APPENDIX A

### HYDROSTATIC WEIGHING FORMULAS

Subjects percentage of body fat was estimated using the following formulas described in McArdle, W.D., Katch, F.I., and Katch, V.L. (1981) Exercise Physiology: Energy, Nutrition, and Human Performance, Philadelphia, Lea and Febiger.

Archimedes' Principle allows us to determine an objects density when submerged in water. This formula is expressed:

$$D_b = M_a \times D_w / (M_a - M_w - RV \times D_w)$$

Where     $M_a$  = Body weight in kilograms  
           $D_w$  = Water temperature correction  
           $M_w$  = Net underwater weight in kilograms  
           $RV$  = Residual lung volume in liters

Once the density of a body is known, a simplified Siri equation is used. The equation is obtained by substituting the known densities of lean and fat weight, 1.10 g x cc<sup>-1</sup> and .90 g x cc<sup>-1</sup>, respectively into the following equation

$$D = \frac{F + L}{(F/f) + (L/l)}$$

By rearranging the terms, the proportional contribution of F (fat percentage) becomes:

$$F = \frac{1}{D} \times \frac{f \times l}{(1-f)} - \frac{f}{1-f}$$

It's derivation by Berkeley scientist Dr. William Siri is:

$$\text{Percent fat} = \frac{495}{\text{Density}} - 450$$



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